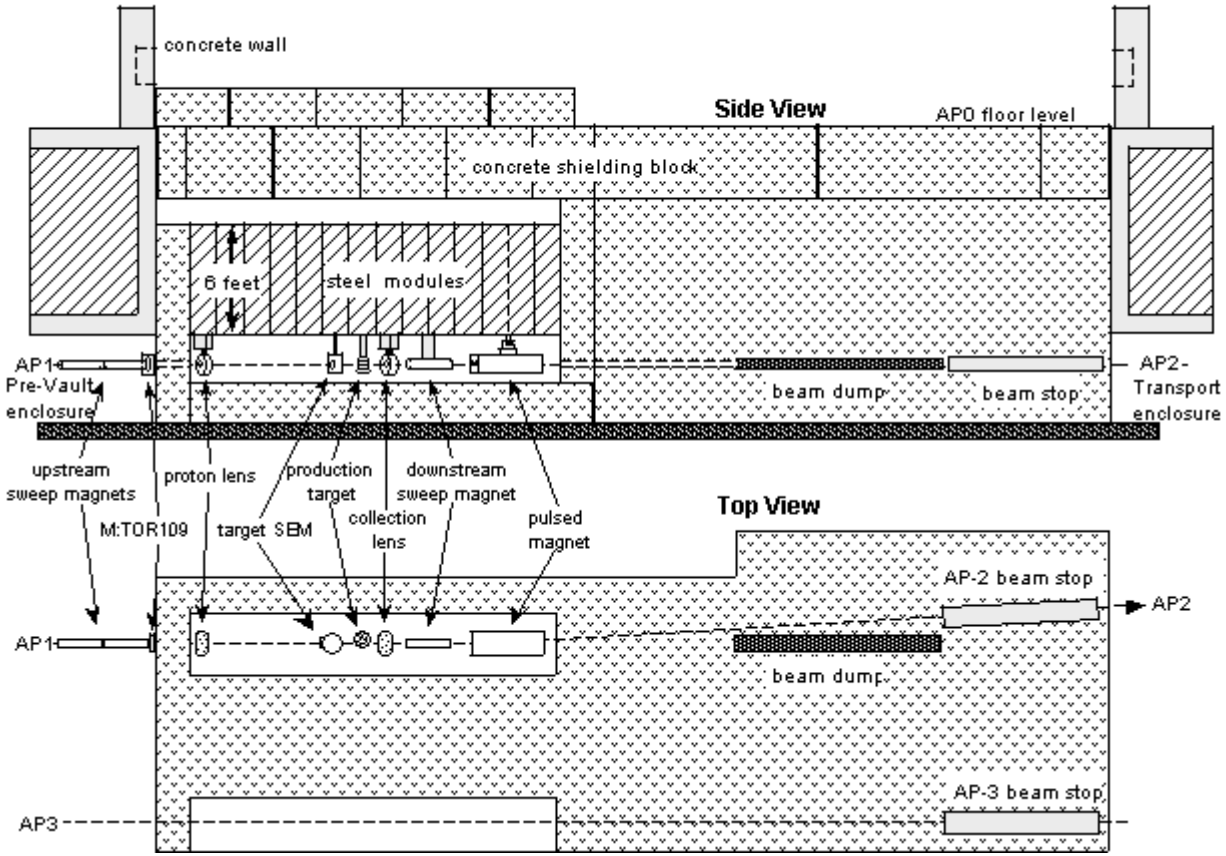
Vault


concrete wall
Side View
AP0 floor level
concrete shielding block
6 feet
steel modules
AP1
Pre-Vault
enclosure
beam dump
beam stop
AP2-
Transport
enclosure
upstream
sweep magnets
proton lens
production
target
downstream
sweep magnet
collection
lens
pulsed
magnet
M:TOR109
target SBM
Top View
AP-2 beam stop
AP2
AP1
beam dump
AP-3 beam stop
AP3

Lithium Lens Upgrade

Objectives

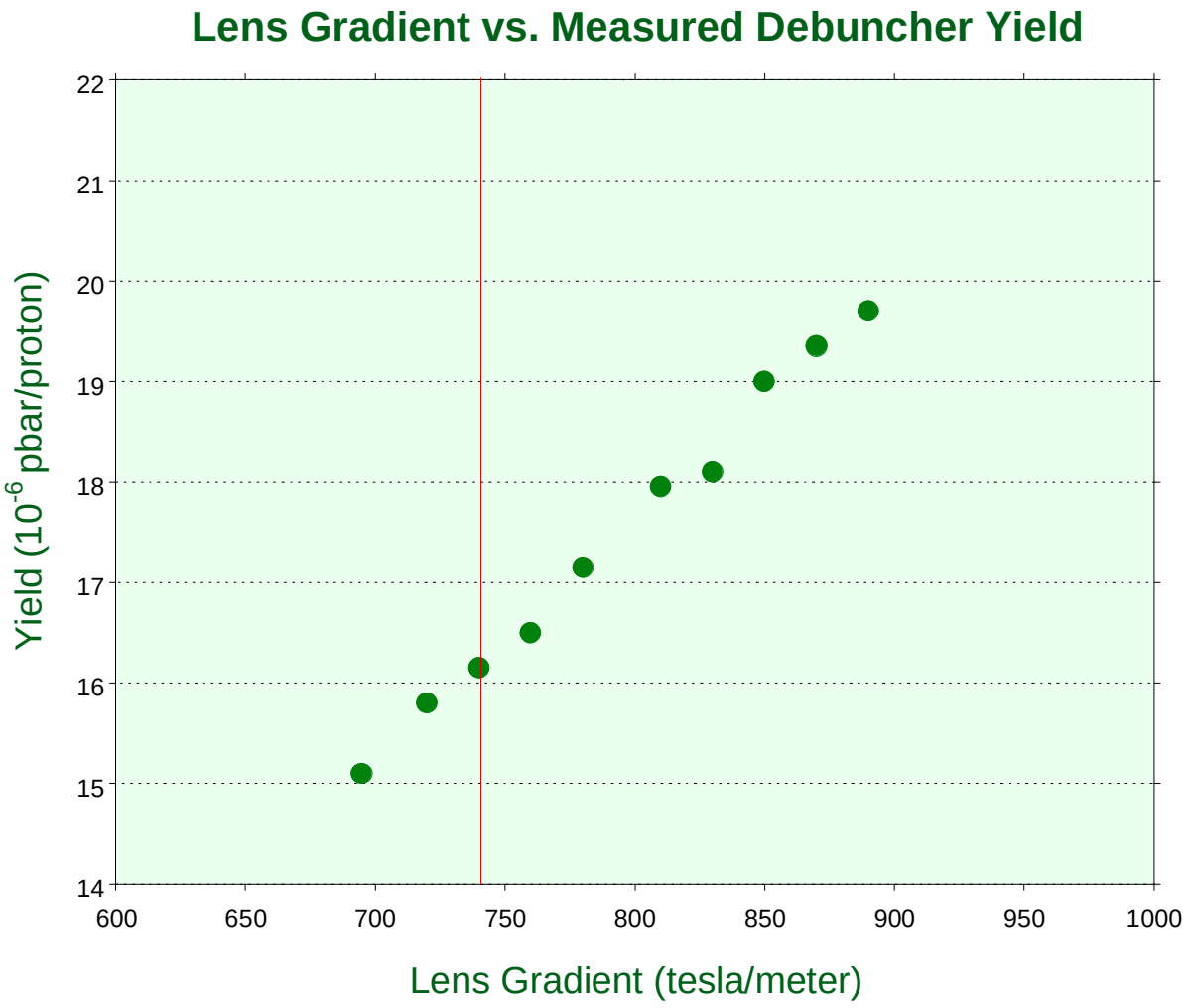
Produce a reliable 1 cm. radius, 100 kg/cm lithium lens

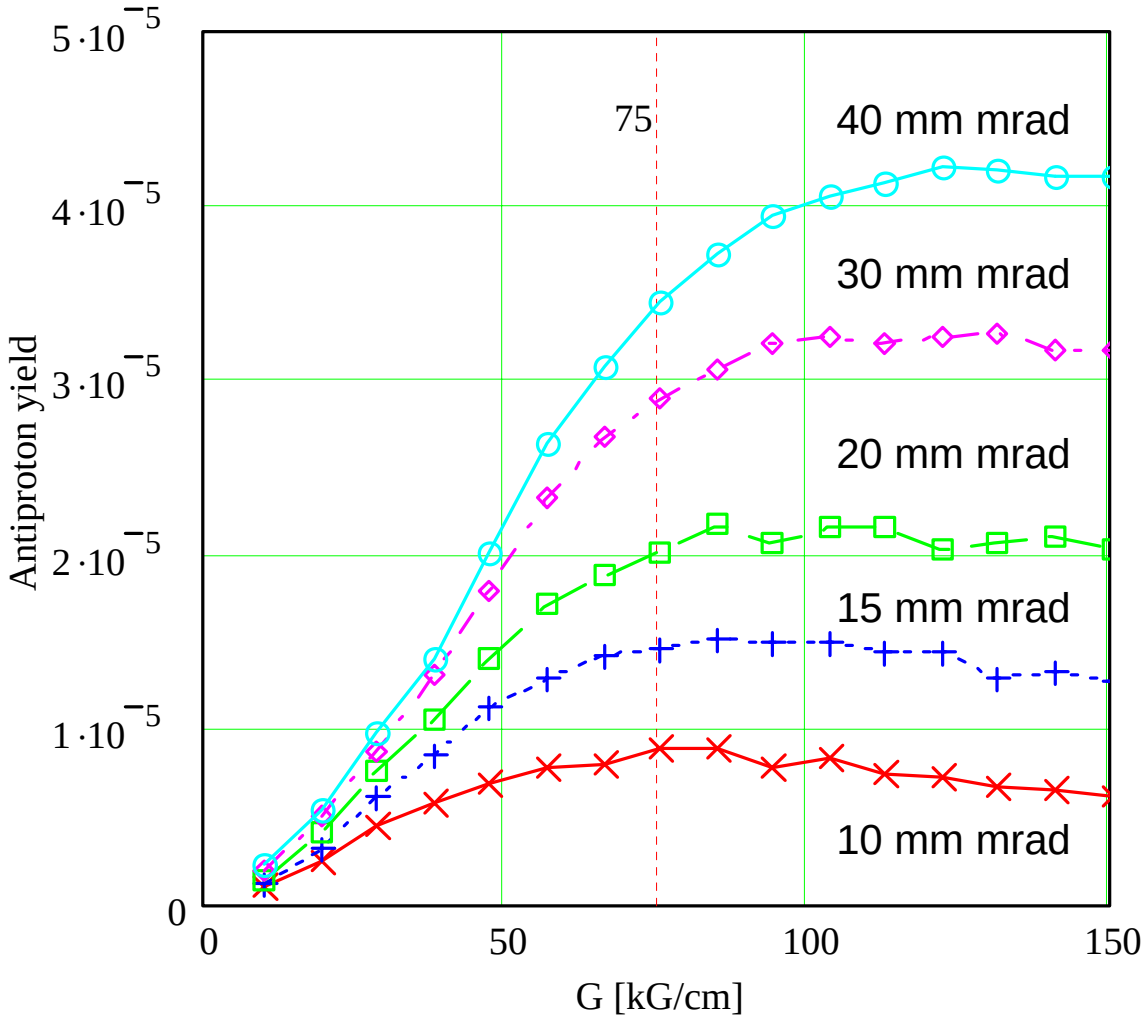
Solid lithium lens

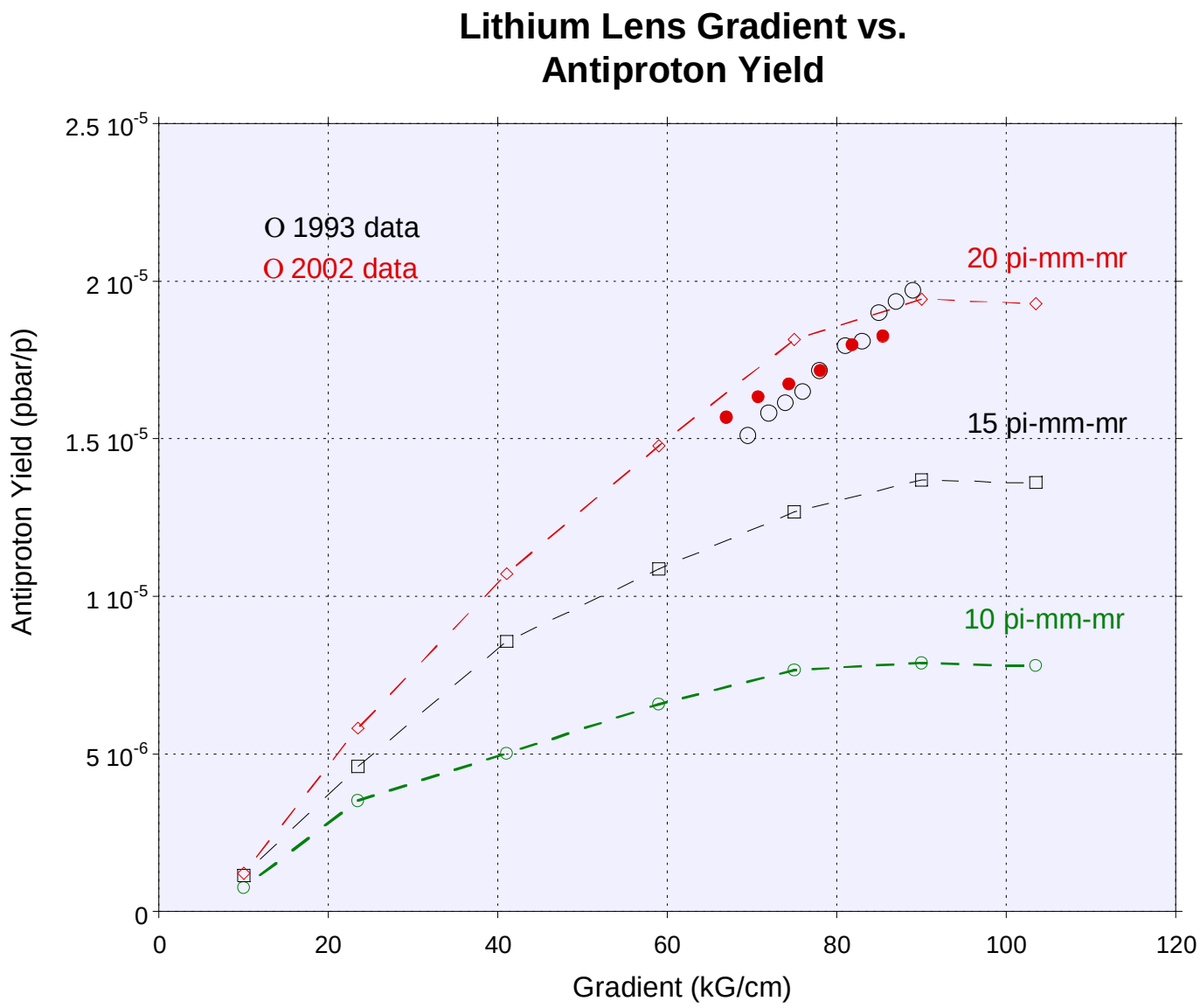
- Disassemble and analyze lenses that have failed
- Create an ANSYS model to better understand mechanical stresses
- Review and improve quality control during lens assembly
- Create an alternative lens design

Liquid lithium lens

- R&D effort at BINP, Novosibirsk
- After successful test, significant effort required to modify apparatus


Lens Gradient vs. Measured Debuncher Yield
Yield (10^{-6} pbar/proton)
22
21
20
19
18
17
16
15
14
600
650
700
750
800
850
900
950
1000
Lens Gradient (tesla/meter)

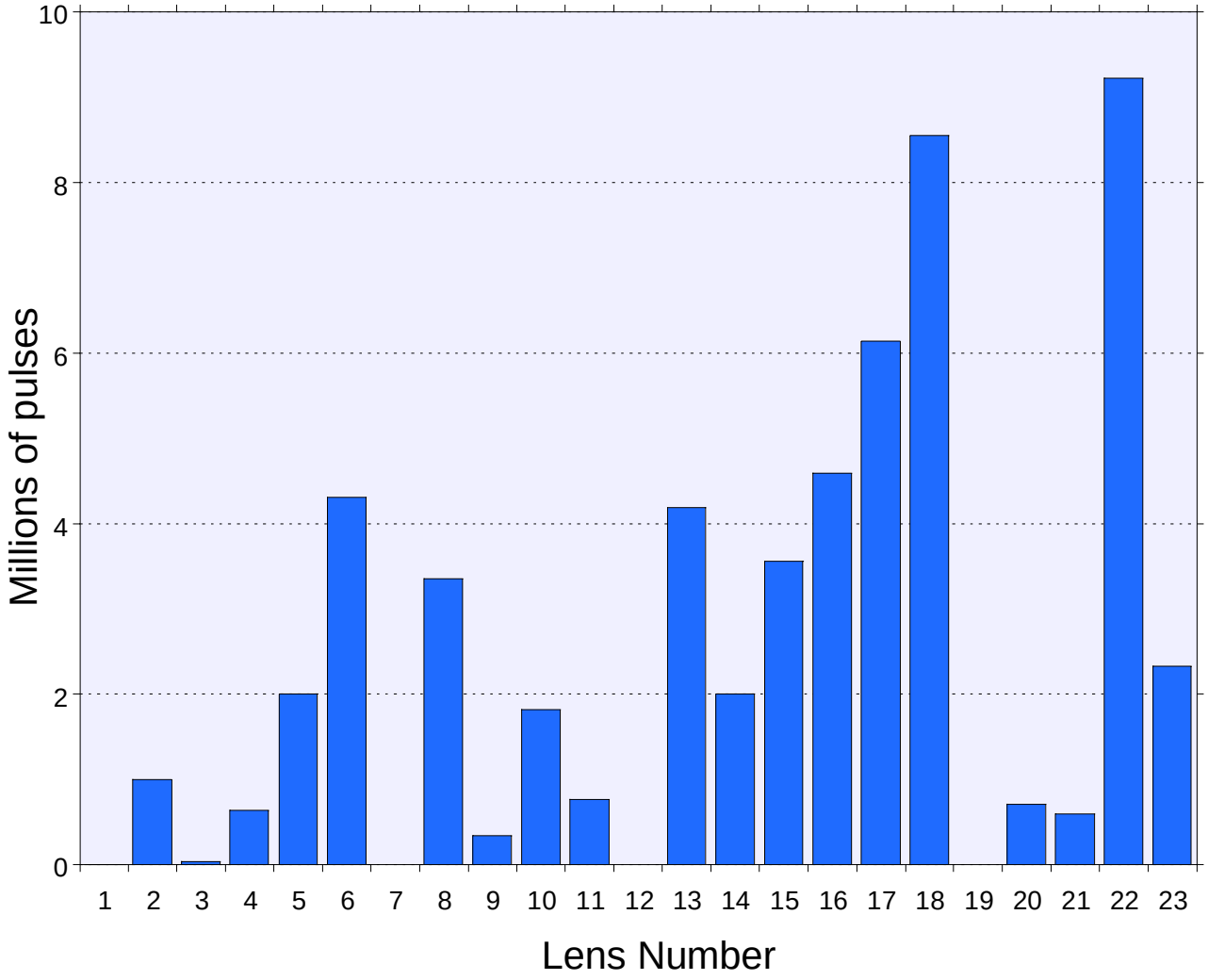

5·10⁻⁵
4·10⁻⁵
3·10⁻⁵
2·10⁻⁵
1·10⁻⁵
0
Antiproton yield
0
50
100
150
G [kG/cm]
75
40 mm mrad
30 mm mrad
20 mm mrad
15 mm mrad
10 mm mrad


Lithium Lens Gradient vs.
Antiproton Yield
Antiproton Yield (pbar/p)
Gradient (kG/cm)
2.5 10-5
2 10-5
1.5 10-5
1 10-5
5 10-6
0
0
20
40
60
80
100
120
1993 data
2002 data
20 pi-mm-mr
15 pi-mm-mr
10 pi-mm-mr

Observed Lens Lifetime

Lens Gradient (T/m)	Average Pulses to Failure
1,000	< 500,000
900	1,000,000
800	3,000,000
740	9,000,000
700	> 10,000,000

Lithium Lens Lifetime



Lithium Lens Upgrade

ANSYS summary for current lens

Analysis of thermal analogue completed and report written
Indicates relatively moderate cyclic stresses, well below fatigue limit
Evidence of lithium separation from titanium septum at high gradient
Model is being refined to include more realistic material properties
Need to understand differences between model and autopsy results
Investigate loads on 18 cm. "long" lens

Lithium Lens Upgrade

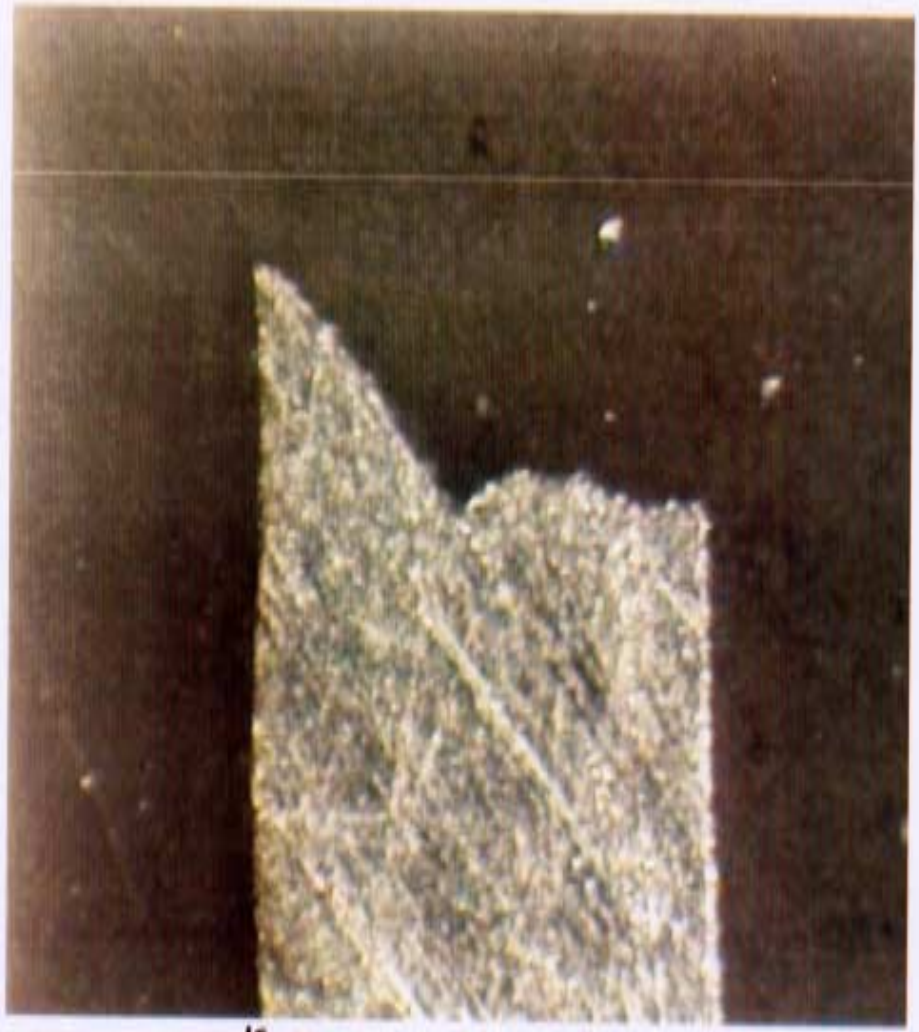
Autopsy results

Lenses scheduled for disassembly and analysis
- Lenses #20 and #21, #26 and Russian lens completely done
- Lenses #17 and #18 disassembled, awaiting analysis
- Lens #16 awaiting disassembly
- Lens #22 cooling down

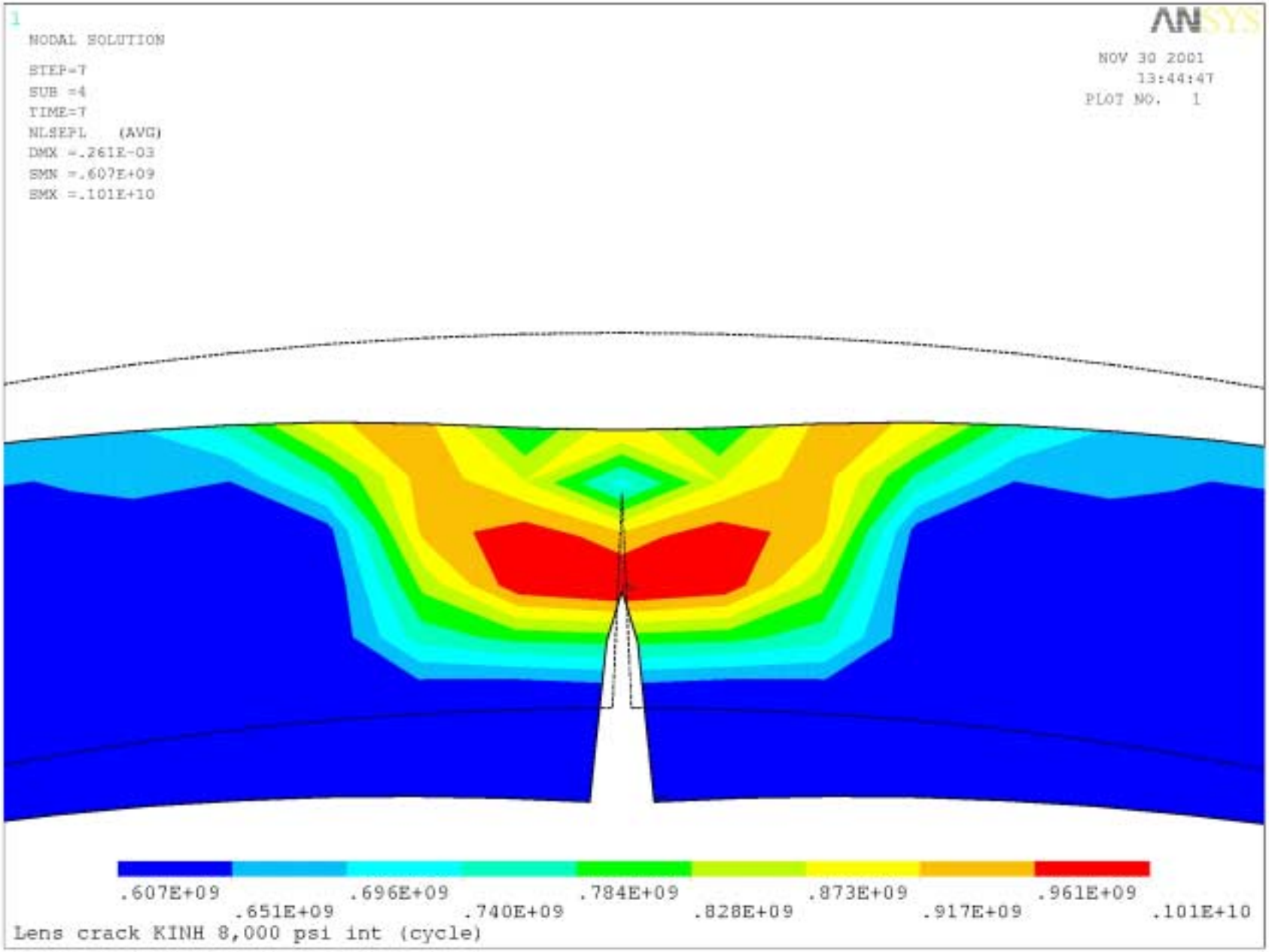
Two general failure modes to inner septum
- Axial intergranular fracture followed by a ductile fracture
  - *Intergranular nature of crack more consistant with corrosion*
  - *Length of ductile fracture consistant with lower loads from ANSYS*
- Circumferential channels burned through septum
  - *Suggests internal arcing, possibly from Li/Ti separation*
  - *Small cracks may be obliterated after arcing begins*

Multiple cracks and pits found on inside surfaces of septa

#20



#21


1
NODAL SOLUTION
STEP=7
SUB =4
TIME=7
NLSEPL (AVG)
DMX =.261E-03
SMN =.607E+09
SMX =.101E+10
ANSYS
NOV 30 2001
13:44:47
PLOT NO. 1
.607E+09
.651E+09
.696E+09
.740E+09
.784E+09
.828E+09
.873E+09
.917E+09
.961E+09
.101E+10
Lens crack KINH 8,000 psi int (cycle)

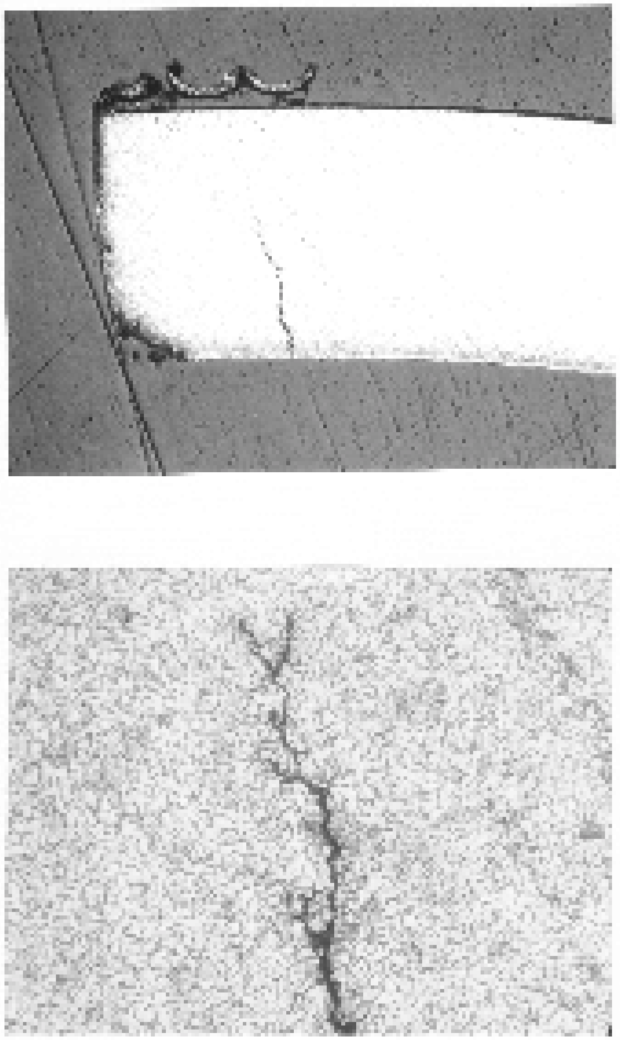


FIGURE 2 Magnification: 50X (top) 200X (bottom)
Photomicrographs showing the intergranular crack tentatively identified as "A" originating on the lithium side of the inner tube of Lens 26.

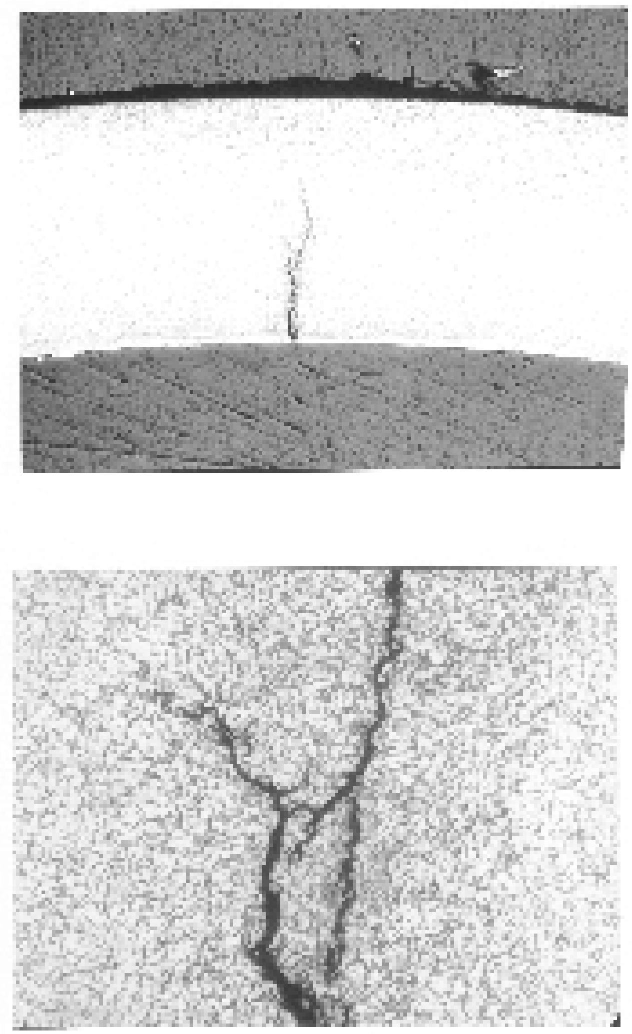


FIGURE 4 Magnification: 50X (top) 200X (bottom)
Photomicrographs showing the intergranular, branching crack tentatively identified as "B" originating on the lithium side of the inner tube of Lens 26.

Lithium Lens Upgrade

Quality Control Improvements

Lens Fill

- Added instrumentation to lens body
- Improved data acquisition
- Changed strain gauges to improve accuracy
- Pressure transducers upgraded
- Created dummy lens to calibrate instrumentation
- R&D of lens seals and lithium properties

Lens Preparation

- Improved electron beam welding techniques
- Lithium handling procedures changed to minimize contamination
- Created new septum cleaning procedures to avoid stress-corrosion cracking

Lithium Lens Upgrade

Prototype High Gradient Lens

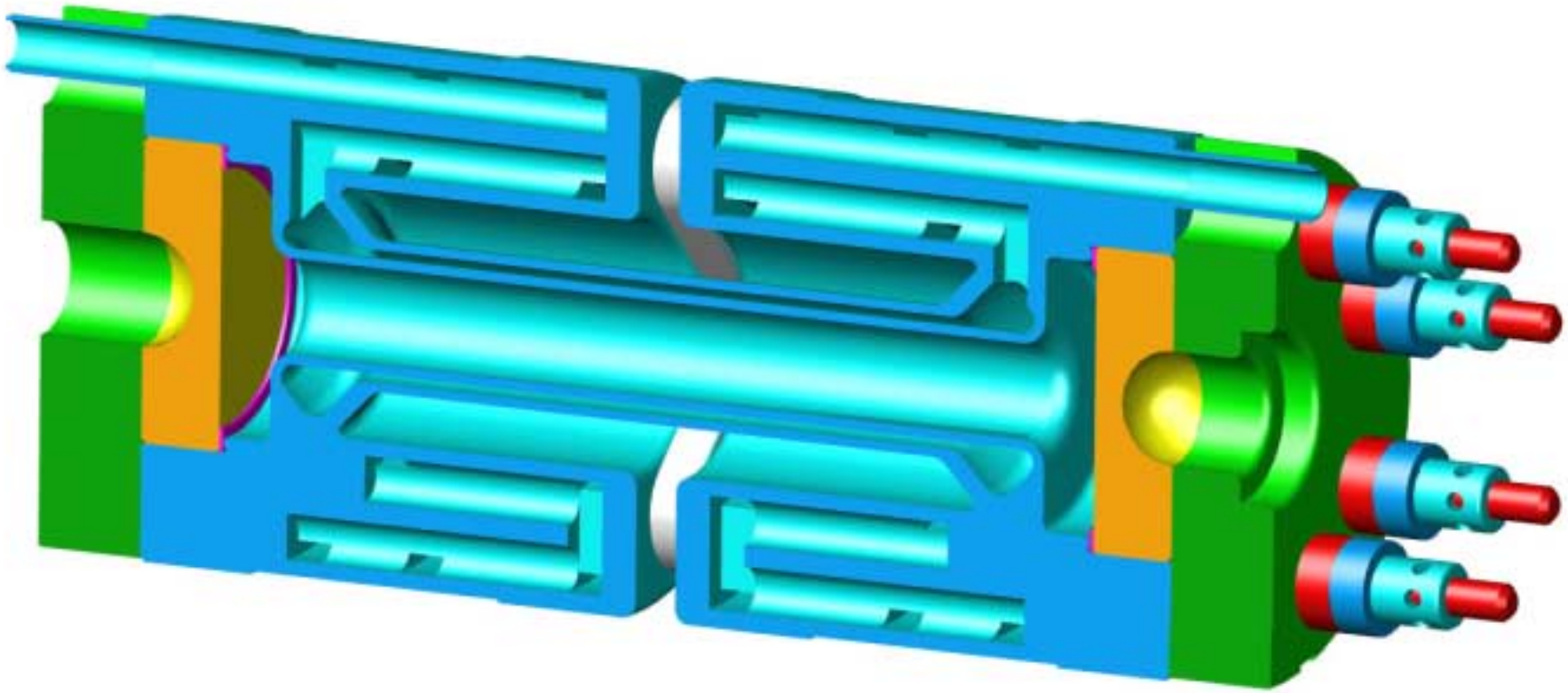
Description

- Lens body and septum both made of titanium
- Eliminates complicated seal between septum and seal body
- Diffusion bonding utilized for joining titanium pieces
  - Possible problems with integrity of central bond
  - Fatigue testing of diffusion bonded samples underway
- Septum construction simplified
- Thicker inner septum
- First generation diffusion bonded lens is in final machining stage
- Second generation design eliminates central joint

ANSYS analysis

- Analysis completed, report forthcoming
- Model needs same refinement as current analysis
- Indicates Li/Ti separation problem and stresses similar to current lens

High Gradient Solid Lens Prototype Design



Lithium Lens Upgrade

Liquid lithium lens

Advantages

Lower mechanical stresses on septum from lithium in liquid state
Functional buffer volume to reduce pressure from thermal expansion
Liquid lithium circulated to remove heat from lens
Better regulation of lens preload

Disadvantages (don’t get me started)

Challenges associated with circulating liquid metal
Locking valves required to prevent damage to circulating system
Reliability of such a complex system will probably be much lower
Elaborate control system required to regulate temperature and pressure
"Bench top" set-up will need to be heavily modified to fit in vault
Liquid lithium system much more hazardous than solid lens

Liquid Lithium Lens

Original Schedule

Phase	Goal	Completion Date
1a	Conceptual Design	12/31/97
1b	Produce drawings and report	3/31/98
2a	Assemble liquid lithium lens	12/31/98
2b	Design power supply	12/31/98
3	Test lens to 1,300 T/m, ship to Fermilab	12/31/99
4	Testing at Fermilab, build spare lens	6/30/00

Lithium Lens Upgrade

Summary

Solid lithium lens

- Lens autopsy
  - Lenses 20, 21, 26 and Russian lens have been disassembled and analyzed
  - Lenses 17 and 18 will be analyzed in the next two months
  - Lens 16 and 22 will be disassembled in the next few months.
- ANSYS modeling
  - Analysis complete on current lens design, refinements to model planned
  - Prototype lens analysis complete, report being generated
- Prototype Lens
  - First prototype has been bonded, machining is underway, fill to follow
  - Second prototype is being designed with no central joint
  - First prototype will be tested to failure while second is being built
- Quality Control
  - Lenses 27 and 28 have been assembled with the new techniques
  - Lens 27 has been filled with the new system
  - Titanium embrittlement being investigated

Liquid lithium lens

- R&D effort may continue BINP
- The liquid lithium lens is no longer expected for use in Collider Run II